

Interlaboratory Comparison of Josephson Voltage Standards (JVS) between NIST and Lockheed Martin Astronautics (LMA)

Y.H.Tang*, W.B.Miller**

*National Institute of Standards and Technology, Gaithersburg, MD 20899, USA

**Lockheed Martin Astronautics, Denver, CO 80201, USA

Abstract¹

Two JVS systems operated at NIST and LMA were compared by using four travelling Zener standards. A MAP protocol was adopted for the comparison. The mean difference between the measurements of the two laboratories was found to be 0.059 μV with an expanded uncertainty of $\pm 0.218 \mu\text{V}$ with 95 % confidence.

Introduction

An intercomparison of Josephson voltage standards (JVS) between NIST and LMA was carried out from May 28, 1999 to June 30, 1999. The main purpose of the intercomparison was to establish traceability of LMA's JVS to the U.S. national representation of the SI volt for a JVS intercomparison organized by the National Conference of Standard Laboratories (NCSL). In the past, corrections for environmental effects on Zener standards due to pressure and temperature were not based on independent determinations of these effects. Rather, the environmental effect such as from pressure was treated as a fit parameter in the data analysis [1]. The second purpose of the NIST-LMA intercomparison was to test the technique of applying pressure corrections for travelling Zener standards in order to improve the uncertainty of the comparison.

Experimental description

A set of four Fluke 732B travelling Zener standards² was measured at 10 V against the JVSs at NIST and LMA using measurement assurance program (MAP) procedures. NIST received the Zener standards on May 27, 1999. The first round of measurements at NIST was carried out from May 29 through June 7. LMA performed its measurements between June 10 and June 21. NIST started its second round of measurements on June 23 and finished the intercomparison on June 30, 1999. All the shipments were handled by overnight express delivery. For a single point measurement of a Zener output, an integration time of 100 s was used for averaging at NIST, and 20 s at LMA. An established procedure was used to minimize the thermal voltages existing in the wires and contacts between the scanner and Zener standards. Each Zener output was measured consecutively twice, once

normally and once with the positive and negative outputs reversed. Four low-thermal reversing switches were attached directly to the Zener terminals for this purpose. During the first set of measurements at NIST, it was noticed that the reversing switches attached to two Zener standards exhibited excessive offset voltages. As a result, these two switches were not used during the subsequent measurements. Instead, the polarity of the two affected Zener standards was changed manually with great caution. The mean difference of the paired Zener outputs was used to derive a single measurement for the data analysis. A total of 10 pairs of measurements were taken in the first round at NIST. LMA took 12 pairs of measurements. In the final round at NIST, 7 pairs of measurements were taken.

The pressure coefficients of the four Zener standards for the NIST-LMA intercomparison have been measured at NIST and the Sandia National Laboratory (SNL). The results were consistent within the uncertainty of the measurements. The Zener outputs depend linearly on the pressure, and they track the variations in the ambient pressure very closely. The mean value of the NIST and SNL measurements of these coefficients was used to correct the output voltage of each Zener to a standard atmospheric pressure of 1013.25 hPa. The four pressure coefficients used are listed in Table 1.

Table 1. Pressure coefficients and standard deviations for four Zener standards

	Z1	Z2	Z3	Z4
Coefficient (nV/hPa)	-0.714	-1.720	-1.186	-0.821
1 σ (nV/hPa)	0.039	0.036	0.041	0.041

Results

In analyzing the data, we first computed the average value for each pair of positive and negative Zener outputs. The corrections due to the difference in barometric pressure were then made to the NIST and the LMA measurements. The corrected Zener output is calculated using Eq.(1),

$$V(\text{corrected}) = V(\text{paired}) - C_P(P-1013.25)/1000 \quad (1)$$

where C_P is the pressure coefficient in nV/hPa, P is the pressure in hPa, $V(\text{corrected})$ and $V(\text{paired})$ are in μV , and 1013.25 is the reference pressure in hPa. Second, it was assumed that during the time period for the comparison the travelling Zener standards would be drifting linearly with time. A least-sum-of-squares (LSS) fit was applied to the NIST data. The fit results for the four travelling Zener standards are listed in Table 2.

¹This work was performed partly at NIST in the Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce, and partly at LMA, Metrology Laboratory.

²Certain commercial equipment, instruments, or materials are identified in this report in order to facilitate understanding. Such identification does not imply recommendation or endorsement by NIST or LMA, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Table 2. Drift rates of the travelling Zener standards and associated standard deviations

	Z1	Z2	Z3	Z4
Drift rate (nV/day)	20.32	15.40	25.42	39.86
1 σ (nV/day)	2.03	2.68	1.76	1.07

Figure 1 shows the data of Z4 from NIST and LMA, and a LSS fit line using NIST data only.

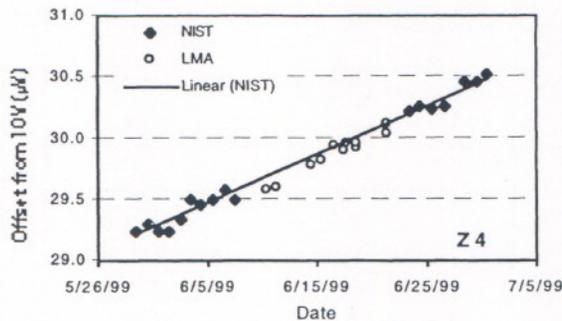


Figure 1. Data of Z4 from NIST and LMA. The data have been adjusted to the standard atmospheric pressure of 1013.25 hPa.

Third, it was assumed that the travelling Zener standards drift with the same rate at LMA as at NIST. An offset between LMA and NIST for each Zener standard was calculated based on LMA's measurements and on the drift rate from the NIST data by Eq.(2)

$$\Delta(LMA - NIST) = \frac{\sum [(V_i(LMA) - V_i(predict))]^2}{12} \quad (2)$$

where $V_i(LMA)$ is the i^{th} measurement by LMA, $V_i(predict)$ is the i^{th} calculated Zener value at the time when the LMA measurement was taken using the NIST drift rate, and 12 is the total number of paired measurements made by LMA. The difference between LMA and NIST measurements for each travelling Zener standard is listed in the last row of Table 3. The mean difference of the four standards was found to be 0.059 μV . Finally, the uncertainty components of the intercomparison were evaluated and the results are listed in Table 3. The Type A uncertainties of NIST and LMA were calculated based on the residuals relative to the LSS fit line. The total Type A uncertainty for each Zener is the root-sum-square (RSS) of the NIST and LMA Type A measurement uncertainties. There was a Type B uncertainty contribution from the pressure coefficient measurements. The uncertainty, u_P , due to the pressure difference between NIST and LMA is given by Eq.(3)

$$u_P = u_{CP}(P_{NIST} - P_{LMA}) \quad (3)$$

where u_{CP} is the standard uncertainty of the pressure coefficient measurements whose results are listed in Table 1, and P_{NIST} and P_{LMA} are the mean pressures at NIST and LMA respectively, during the time when the respective measurements were taken. This Type B uncertainty contribution is listed in Table 3 for each Zener standard.

Table 3. The difference between LMA and NIST, and the uncertainty components, all in μV

	Z1	Z2	Z3	Z4
NIST Type A	0.024	0.031	0.021	0.013
NIST Type B	0.007	0.007	0.007	0.007
LMA Type A	0.038	0.026	0.021	0.012
LMA Type B	0.034	0.034	0.034	0.034
Type B due to C_p	0.007	0.006	0.007	0.007
LMA - NIST	0.090	-0.014	0.226	-0.064

The combined expanded uncertainty u_c of the intercomparison with 95% confidence is calculated using Eq.(4).

$$u_c = \sqrt{(2.13u_A^{NIST})^2 + (2.20u_A^{LMA})^2 + (3.18u_B^{LMA-NIST})^2 + (2u_B^{LMA,NIST,pressure})^2} \quad (4)$$

Eq.(4) includes contributions from the pooled Type A uncertainty of the NIST and LMA measurements, the Type uncertainty of the LMA-NIST difference of the four Zener standards (the standard deviation of the mean from the four difference measurements listed in the Table 3), the RSS Type uncertainty of the NIST, LMA JVS systems, and the pressure coefficient measurements. Each of the Type A and Type B contributions is associated with a certain Student t factor for a 95 % confidence level based on the degrees of freedom (DOF) in the calculations [2]. The calculated uncertainty contributions are listed in Table 4. The combined uncertainty at the 95 % confidence level is calculated to be 0.218 μV .

Table 4. Uncertainty Summary of NIST-LMA intercomparison

Source	Uncertainty (μV)	DOF	Student t
Pooled Type A of NIST, u_A^{NIST}	0.012	15	2.1
Pooled Type A of LMA, u_A^{LMA}	0.013	11	2.2
Standard deviation of mean of four Zener differences $u_B^{LMA-NIST}$	0.064	4	3.1
Type B uncertainty from NIST, LMA JVS systems and pressure, $u_B^{LMA,NIST,pressure}$	0.035		2
Combined uncertainty of 95 % confidence	0.218		

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References

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